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Cost over Progress Based Energy-efficient Routing Protocol over Virtual Coordinates in Wireless Sensor Networks

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Dans un réseau sans fil (réseau *ad hoc* ou de capteurs), la durée de vie du réseau est dépendante des batteries des nœuds. Ainsi, utiliser des protocoles qui minimisent la consommation énergétique s'avère important. Dans cet article, nous supposons que les nœuds ne connaissent pas leurs coordonnées géographiques. Nous proposons un protocole de routage VCost basé sur un système de coordonnées virtuelles qui minimise la consommation énergétique à chaque saut. Il s'avère que VCost améliore grandement la consommation énergétique par rapport à d'autres protocoles de routage basés sur des coordonnées virtuelles tout en égalant leur taux de livraison.

Keywords: Geographical Routing, Virtual Coordinates Based Routing, Wireless Networks

1 Introduction

Sensor networks are specialized ad hoc networks composed of a large number of self organizing devices. They are used in a wide range of applications, such as monitoring, security, and data-gathering. These applications have two challenging issues in common *i. e., energy savings* and *position-awareness*. In this paper, we address these two key issues. Nodes, in sensor networks, rely on batteries with limited capacity, thus the most important criteria when designing communication protocols is to optimize their energy consumption to extend the life of the sensor device and extend the reliability of the underlying network. In this framework, routing protocols based on geographic information of the sensors have been proposed as a viable alternative to existing routing protocols for ad hoc networks in order to reduce the overhead of maintaining routing tables and to avoid the cost of flooding. However, such a solution requires that the sensors be aware of their geographic (physical) position which can be obtained by equipping all the sensors with costly GPS devices. However, even such an alternative may not be a reliable solution since GPS reception might be obstructed by static obstacles *i. e.*, nodes may be deployed indoors. A cheaper alternative is to consider the problem of inferring nodes location in sensor networks in which no node is aware of its physical location. Proposed solutions such as in [CCDU05, FGG$^+$05] are aimed at routing by deriving and using virtual coordinates. However, none of the above cited papers consider or optimize the energy consumption in their proposed algorithms.

In this paper, we are interested in energy efficient routing in sensor networks where nodes are not aware of their physical locations. Xu et al., in [SL01], compute the optimal transmission radius that minimizes the total power consumption for a routing task in sensor network. In this work, we extend this result and present an energy aware routing algorithm based on virtual coordinates. We compare the performance of our proposed method to the one of several geographic routing algorithms and show that our algorithm is efficient in terms of energy saving and hit rate (success rate of a message to reach its destination).

The rest of the paper is organized as follows. In Section 2, we present a brief summary of existing geographic routing algorithms relevant to our work. In Section 3, we present our contribution, a cost efficient routing algorithm over virtual coordinates. In Section 4, we compare the performance of our proposed method to alternative routing algorithms presented in Section 2. Finally we conclude and present future work extensions in Section 5.

2 Related Works

Several geographic routing approaches that rely on virtual coordinates have been proposed. To define a virtual coordinate system, one of three options can be adopted. First, one can assume that nodes have knowledge of their neighbors and based on this information a coordinate system is defined. Second, one can equip a subset of nodes with a satellite receiver and use these *landmarks*. In this case, to infer the position of the remaining nodes, it suffices to know their distance relative to the *landmarks*. Note that several distance measures, such as the Euclidean and the Hamming distances, have been used in the literature. A Virtual Coordinate assignment (VCap) system is proposed in [CCDU05] as a third option when no location information is available.

We focus on the following routing algorithms : MFR, Glider, VCap Routing and Cost-over progress Routings.

- *Most Forward Routing (MFR)*. In this greedy approach [TK84], the source node forwards the message to the node that is closest to the destination. This is a simple localized algorithm however it does not guarantee delivery. This approach can be trapped in a local minimum and the algorithm fails to find a path to the destination. Thus the hit rate is very low. This algorithm works well in a dense graph.
- *Gradient landmark based routing (Glider)*. In [FGG$^+$05] nodes are partitioned into tiles and a set of well dispersed nodes are identified as *landmarks*. Virtual coordinates are then given to each node based on their centered square-distance, otherwise known as the variance, from each *landmark*. Based on the virtual coordinate system, the distance between two nodes, the centered virtual distance is computed.
- *VCap*. In [CCDU05] a system of virtual coordinates based on 3 *landmarks* is proposed. Nodes are assigned a triplet of coordinates given as the number of hops the node is distant from each *landmark*. A more accurate coordinate system can be established as the number of *landmarks* increases [BPdA$^+$07]. Then, nodes use a greedy routing, like in *MFR* based on the Hamming distance on these coordinates.
- *Cost Over Progress*. In [KNS06], a localized energy-aware algorithm where nodes are equipped with GPS receivers is proposed. Each node makes a routing decision on the basis of its location, its neighbors and the destination. A node forwards the packet to the neighbor closer to the destination such that the ratio of the energy consumed to the progress made (measured as the reduction in distance to destination) is minimized. Generally, the energy consumed E, depends on the transmission range r and the overhead c that is due to signal processing and it is equal to $\mathrm{E} = r^\alpha + c$ if $r \neq 0$ and zero otherwise, α is a real constant greater than 1 and it represents the signal attenuation. In [SL01] the optimal transmission radius, r^*, that minimizes the total power consumption for a routing task is computed and it is equal to : $\mathrm{r}^* = \sqrt[\alpha]{\frac{\mathrm{c}}{\alpha-1}}$,

3 Cost over Progress over Virtual Coordinates

The framework of our proposition is similar to VCap. Several nodes, $L_1, , \ldots, L_k$ with $k \geq 3$, in the network are distinguished as *landmarks*. An arbitrary node x knows its distance vector $l(x) = (l_1, \ldots, l_k)$ where l_i is the hop-distance between x and L_i. From vector $l(x)$, the node generates a so-called virtual coordinates $c(x) = (x_1, \ldots, x_m)$ with $m \geq 2$. Note that in general $m \leq k$, in our study $m = k$. This computation function is denoted by Γ. For this paper, we consider two Γ functions : the identity denoted by Γ_{id} ($x_i = l_i$) and the "centered virtual coordinates" used in [FGG$^+$05] and denoted by Γ_{cvc} ($x_i = l_i^2 - \mu$ where $\mu = \frac{1}{k}\sum_{i=1}^{k} l_i^2$). We suppose that each node x knows the virtual coordinates of each node in its neighborhood ($N(x)$).

To route a packet to destination d, a node extracts the virtual coordinates of d from the packet and chooses a forwarding node in its neighborhood. We propose to use "cost over progress" presented in [KNS06]. The idea is that the current node x chooses node $y \in N(x)$ which minimizes $\frac{\mathrm{cost}(x,y)}{\mathrm{progress}(x,y,d)}$ where $\mathrm{cost}(x,y)$ represents the "cost" for x to send the message to its neighbor y, and where $\mathrm{progress}(x,y,d)$ is the progress in the routing task. Basically, the progress can be expressed as the difference $dist(x,d) - dist(y,d)$ where $dist(u,v)$ is the "distance" between u and v. For this protocol to work, the current node has to limit its choices to neighbors with positive progress.

In this paper, we consider two cost functions : $\mathrm{cost}_1(x,y) = 1$ when node x is not able to adapt its communication range and $\mathrm{cost}_e(x,y) = |xy|^\alpha + c$ otherwise. The distance $|xy|$ is the Euclidean distance between x

and y. For the distance function $dist$, we consider three different functions. The first one, called "Hamming distance", defined by $dist_h(x,y) = \sum_{i=1}^{m} |x_i - y_i|$. The second function, called "Euclidean distance", defined by $dist_e(x,y) = \sqrt{\sum_{i=1}^{m}(x_i - y_i)^2}$. The last distance function we study is called "Square Euclidean" distance and it is simply defined by $dist_{se}(x,y) = dist_e(x,y)^2$.

By combining the functions Γ, the distance $dist$ and the cost functions, we obtain a family of protocols. For instance, the triplet $(\Gamma_{id}, dist_h, \mathrm{cost}_1)$ corresponds to protocol VCap. For the other protocols, we consider the cost function cost_e which is omitted, thus we use the following notations : VCost for $(\Gamma_{id}, dist_h)$, VeCost for $(\Gamma_{id}, dist_e)$, VseCost for $(\Gamma_{id}, dist_{se})$, CVCCost for $(\Gamma_{vcv}, dist_h)$, CVCeCost for $(\Gamma_{vcv}, dist_e)$ and CVCseCost for $(\Gamma_{vcv}, dist_{se})$.

4 Experimental Results

To eliminate the effect of the MAC layer on our results, we use our own C simulator that assumes an ideal MAC layer, *i.e.* no interferences and no packet collisions. The simulated network can be described as follows. Nodes are randomly deployed in a 1×1 square using a Poisson Point Process (node positions are independent) with intensity $\lambda = 500$ (each node has 15 neighbors on average). These nodes have the same transmission range, $R = 0.1$, therefore, two nodes are connected by an edge if and only if their Euclidean distance is at most R (assuming a Unit Disk Graph). Finally, the *landmarks* are randomly selected from the network nodes. We run the simulator using the routing algorithms for the same samples of node and landmark distribution and study their performance under the family of protocols described in Section 3. First, we compare the delivery rate of every protocol. The results obtained are within a 95% - confidence interval. Figure 1 shows the success (hit rate) achieved by the routing schemes. Clearly, only the protocols using the d_h as the distance function (VCost and CVCCost) succeed in delivering messages.

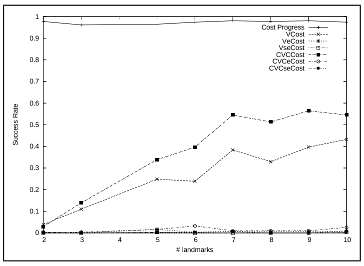
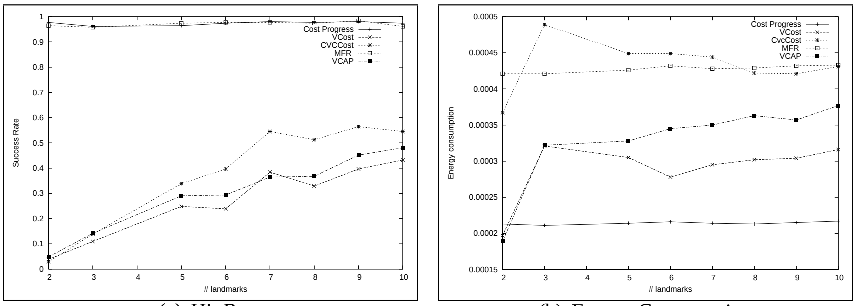


FIG. 1: Hit Rate using different coordinates and distance evaluations.

Our results show that protocols using d_h as the distance function (VCost and CVCCost) achieve a better hit rate than the alternatives. Therefore we compare them to protocols using geographic distance (MFR and Cost-Progress Routing protocols) and to VCap (MFR using Hamming distance over hop distance coordinates). Figure 2 shows our results. As shown in Figure 2(a), our protocols achieve the same hit rate as VCap but VCost is more energy efficient (see Figure 2(b)). VCap however, achieves a better hit rate [CCDU05]. This is due to the fact that we randomly select the landmarks, while in [CCDU05], the landmarks are positioned on a circle around the network nodes. For each protocol we compute the routing path from a given source to a given destination (see Figure 3). Our results show that VCap and MFR take long edges in order to move as close to the destination as possible while Cost-Progress based Routing and VCost try to minimize the energy consumption and follow edges with length as close as possible to the optimal length.

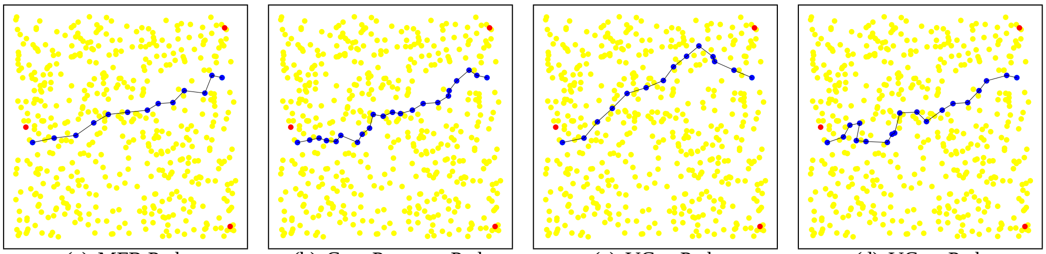
5 Conclusion and Future Work

In this paper, we show how to introduce energy efficiency in position-based routing over virtual coordinates. Our protocol VCost improves significantly energy consumption and preserves the small percentage of successful routings. In our future work, we plan to study the computation of virtual coordinates in order to increase both the success rate and the energy savings. Another interesting problem to consider is self-organization and election of *landmarks*.



(a) Hit Rate (b) Energy Consumption

FIG. 2: Hit Rate and Energy consumption of the family of protocols.



(a) MFR Path (b) Cost-Progress Path (c) VCap Path (d) VCost Path

FIG. 3: Path followed between a pair of nodes by each protocol. *Landmarks* are shown in red. In plots (a) and (b) we use geographic coordinates and in (c) and (d) we use virtual coordinates

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